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Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia

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A B S T R A C T

South Asian countries face mounting challenges in meeting the growing demand for food, water, and energy for a rapidly growing population. Countries have provided policy support to increase cereal production, including providing incentives by subsidizing water and energy and guaranteeing rice and wheat prices. While such incentives have increased cereal production, they have also increased the demand for water and energy, led to degradation of the resource base, and contributed to an increase in water-related disease. Despite the inherent interconnections between food, water, and energy production, agencies often work in a fragmented and isolated way. Poor sectoral coordination and institutional fragmentation have triggered an unsustainable use of resources and threatened the long-term sustainability of food, water, and energy security in the region, and also posed challenges to achieving the Sustainable Development Goals (SDGs). Free water and subsidized electricity have not only encouraged overexploitation of resources, they have also led to under-investment in water and energy-saving technologies and approaches and hindered crop diversification and broad-based agricultural growth in line with the comparative advantages. Greater policy coherence among the three sectors is critical for decoupling increased food production from water and energy intensity and moving to a sustainable and efficient use of resources. The nexus approach can enhance understanding of the interconnectedness of the sectors and strengthen coordination among them. But it requires a major shift in the decision-making process towards taking a holistic view and developing institutional mechanisms to coordinate the actions of diverse actors and strengthen complementarities and synergies among the three sectors. A framework is suggested for cross-sectoral coordination and managing the nexus challenges.
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1. Introduction

Although the South Asian countries have made remarkable progress in socio-economic development in recent years, challenges persist in ending hunger and poverty, and ensuring food and nutritional security, an adequate standard of living, access to modern energy, and healthy lives for the vast population. Despite the impressive economic growth over the last decade, South Asia remains home to more than 40% of the world's poor (living on less than USD 1.25 a day) and 35% of the world's undernourished (Sumner, 2012). Some 51% of the population is food-energy deficient (Ahmed et al., 2007) and more than 56% of the world's low-birth weight babies are born in the region (Iqbal and Amjad, 2010). The MDGs remain an unfinished agenda. With less than 5% of the earth's land area, South Asia has to feed about one-fourth of the world's

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population (1.6 billion people). Land, water, and vital ecosystems resources are dwindling, but the population is growing, with the population projected to reach 2.3 billion by 2050 if the present growth rate is maintained. Ensuring food, water, and energy security for the growing population without degrading the natural resource base remains a fundamental development challenge in the region. The Sustainable Development Goals (SDGs) (Annex 1 Table A1) adopted by the global community (UN, 2015) are critically important for South Asia for ensuring food, water, and energy security in a way that does not undermine sustainability for future generations.

Rice and wheat, the staple foods in South Asia, require huge amounts of water and energy. Freshwater, once abundant, is under growing stress due to increased demand for competing uses and growing uncertainty due to climate change (Erikson et al., 2009). About 20% of the population lacks access to safe drinking water (Babel and Wahid, 2008). There is a serious shortage of the energy required to make water available for crop production, for example through groundwater pumping (Shah, 2007). Per capita energy consumption in this region is among the lowest in the world (Chaudhury, 2009). With growing populations, declining agricultural land, increasing stress on water and energy resources, and climate variability, South Asia faces the challenge of how to produce more food with the same or less land, less water, and increased energy prices, while conserving resources and maintaining environmental sustainability (Rasul, 2014). The sustainability of rice production is under threat because of its heavy reliance on water and energy, growing water stress and energy shortages, poor functioning of irrigation systems, and increased competition for water and energy from other sectors.

To feed their growing populations, South Asian countries have pursued policies aimed at achieving national food self-sufficiency through production of staple crops with more intensive use of water, energy, and chemical inputs (Alauddin and Quiggin, 2008). To achieve this, water and energy have been heavily subsidized (Atapattu and Kodituwakku, 2009). These policies have contributed to increased food production, although not necessarily a more nutritious diet, but at the cost of accelerated degradation of critical natural resources such as land, soil, and water, and serious environmental impacts including groundwater depletion, waterlogging, salinity of soil, water pollution, and biodiversity loss (Alauddin and Quiggin, 2008). Because of the intensive energy use, food production has become increasingly vulnerable to changes in the availability and price of energy (Rasul, 2014). The challenges of ensuring food, water, and energy security are further compounded by the potential impacts of climate change on the water regime and on energy use and by increasing competition for land and water for bioenergy and hydropower (Rasul, 2014; Rasul and Sharma, 2015).

Food, water, and energy are inextricably linked in a nexus, and actions in one sector influence the others. Food production requires water and energy; water extraction, treatment, and redistribution require energy; and energy production requires water (Bazilian et al., 2011; Hussey and Pittock, 2012). Food production and freshwater services depend on water, land, and other natural resources, in other words a range of ecosystem services (FAO, 2014; Rasul, 2014; Boelee et al., 2011). Food choices and agricultural practices influence water and energy demand. Similarly, water, energy, and land demand is influenced by different policies, for example those relating to agriculture, energy, land-use, food, fiscal, credit, prices, and subsidies. These relationships are dynamic (Fig. 1). However, policies in South Asia, as in many developing countries, are generally narrowly sectoral, with a disconnect between those for food, water, and energy (Hussey and Pittock, 2012). By ignoring the underlying interdependence of the three sectors, policies sometimes have the unintended consequence of shifting a crisis from one sector to another (Tomain, 2011); and policies and actions taken in isolation, without considering their impact on other sectors, can aggravate resource constraints (Hermann et al., 2012; Scott et al., 2011).

With competing demand for resources and increasing environmental pressure, an important challenge facing the South Asian region is how to minimize conflicts among the three main sectors of food, water, and energy, and promote synergies in policies and instruments. At present, policies and instruments are developed without adequate consideration for the cross-sectoral consequences. The lack of connection between sectoral agencies has created an imbalance between the sectors in terms of demand and supply. The cross-sectoral efforts that have been made have remained linear, such as taking into account water for food or energy for food. While the agricultural policy framework has contributed to an increase in

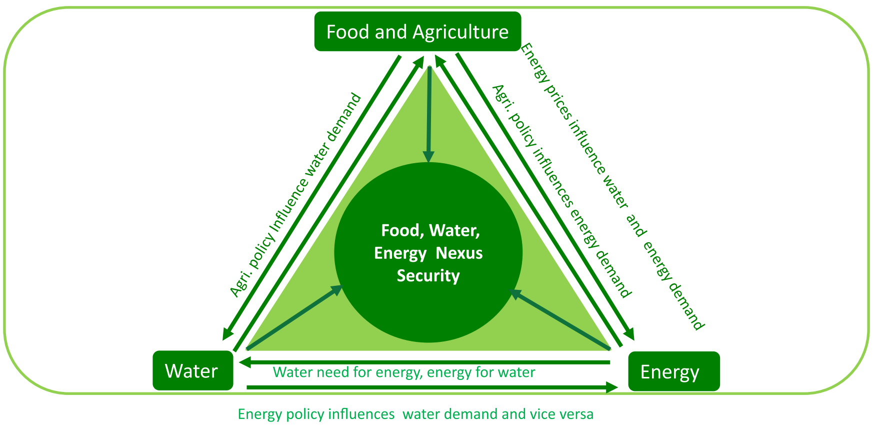

Fig. 1. Dynamic relationship among the food, water, and energy sectors.

food grain production, it imposes a huge pressure on water and energy resources and has weakened the sustainability of agriculture (Pingali, 2007). Subsidies lead to overuse of water and energy and can even be counterproductive. Negative environmental impacts can arise from intensive agriculture, including, for example, waterlogging and salinization of soils and increased incidence of waterborne and water-related diseases (Pingali, 2007). The connections between macro-economic and sectoral policies and cross-sectoral impacts are not internalized into national policies. The cross-sectoral externalities have placed additional pressure on land, water, energy, and other scarce resources and undermined the long-term sustainability of food, water, and energy security (Shah, 2009; Rasul and Sharma, 2015).

The common challenge facing South Asian countries is how to decouple food production from water and energy use intensity

Table 1
Key trends and issues in food, water, and energy security and achieving the SDGs in South Asia.Source: Rasul (2014) and Rasul and Sharma (2015).

Drivers of change	Key trends	Future challenges
Burgeoning human population – the annual population growth rate is about 1.5%, the present population of 1.6 billion is projected to reach 2.3 billion by 2050. Cereal demand is expected to rise from 241 million tonnes in 2000 to 476 t in 2050.	Increasing intensification of water and energy use in food production. Food production will have to increase by 70% in the next 25 years; energy availability will need to increase by 40%, and water by 57% if management is not improved.	Increasing food production without increasing the intensity of water and energy use and environmental degradation.
Growing middle class and rapid urbanization – increased per capita income (4.6–5.6% annually) and fast economic growth (annual average economic growth rate 6–7%) have intensified food, water and energy use.	Changing food preferences from coarse grain to fine types of grain and from grain to animal and horticultural products, which require more energy and water.	Meeting the increased requirement for water and energy for production of increased amounts of meat and fine grain.
Growing requirement for land, water, and energy for different uses.	Growing competition for resources for different uses.	Balancing different needs for land, water, and energy, whilst maintaining environmental integrity.
Increasing intensification of resource use for food production. Energy intensity in agriculture increased from 2.2% in 1989/90–4.0% in 1999/00; the irrigated area is growing by 1.7% annually; fertiliser use grew from 37 kg/ha NPK in 1985–89 in 2005 (increase 4.5% per year).	Dwindling resource base. Slowing of agricultural growth rate.	Providing food, water, and energy to a large malnourished population.
Growing demand for water for agriculture, livestock, energy, urban centers, and industry. Annual water demand is predicted to increase by 55% by 2030 compared to 2005; total water withdrawal for irrigation is expected to increase to 1817 km^3 in 2050 from 1095 km^3 in 2000.	Increasing pressure on water resources for multiple uses; per capita water availability is declining at a rate of 2.1% per annum.	Meeting the competing demands for water for agriculture, domestic use, industry, energy, and the environment and ecosystems.
Declining performance of canal irrigation; subsidies on energy for groundwater irrigation.	Increasing individualization of irrigation systems and increasing community participation in irrigation management. Increased dependence on groundwater for food production; about 70–80% of agricultural production depends on groundwater.	Improving the efficiency of irrigation water and energy use.
Increasing costs for securing water availability such as high costs of groundwater pumping due to high fossil fuel prices and a declining groundwater table.	Increasing financial burden to farmers.	Making agriculture economically viable.
Growing demand for energy – demand increasing at a rate of 5% per annum mainly for households and industry, expected to increase further at a rate of 3.2% per annum through 2030.	Growing demand for water and land for energy production.	Providing adequate and reliable energy to a large population without increasing pollution.
Rapid economic growth, industrialization, urbanization.	Increasing imports of fossil fuels, over 80% of energy provided by oil, imports expected to double by 2020.	Ensuring a stable energy supply for food and water security. Reducing fossil fuel imports.
Intensification of energy use in food production – greatly increased electricity consumption in irrigation due to groundwater pumping (e.g. in India, six-fold increase in electricity consumption per 1000 ha cultivated between 1980/81 and 1999/2000).	Growing demand for water and land for energy production, and increasing fossil fuel imports.	Ensuring sufficient reliable and quality energy for agriculture, water, industry and other economic activities.
Many factors encourage use of irrigation – advances in groundwater technologies; declining cost of water extraction pumps; absence of government regulation on ground water irrigation; government subsidies on fuel and electricity for irrigation.	Declining groundwater tables; declining water quality for domestic, agricultural and other uses; Increase in waterborne diseases.	Managing groundwater for food production and controlling overexploitation of groundwater.
Extensive irrigation leading to land degradation and declining soil fertility.	Degradation and loss of productivity of agricultural land; increased use of chemical fertilizers to maintain productivity.	Long-term sustainability of food production, sustaining the natural resource base and a healthy environment.

and environmental degradation to make it sustainable. The planned Sustainable Development Goals (SDGs) of zero poverty (SDG1), ending hunger and food insecurity (SDG 2), ensuring water security (SDG 6), access to modern energy (SDG 7), sustainable economic growth (SDG 8), sustainable consumption and production (SDG12), and conservation, protection, and sustainable use of marine and terrestrial resources and ecosystems (SDGs 14 and 15) are closely interlinked and success in achieving them will depend heavily on ensuring the sustainable use and management of water, energy, land (food), and other natural resources. These factors are not only interdependent, they also both reinforce and impose constraints on one another (Rasul, 2014; Weitz et al., 2014; Rasul and Sharma, 2015; GDI, 2015). The goals are interlinked in different ways. Achieving the goal of food security and ending hunger, for example, depends strongly on achieving the goal of water and energy security which is needed to ensure water and energy is available for food production. Similarly, the ability to achieve the goal of water and energy security will largely depend on the ways in which food is produced, processed, transported, and consumed (Hussey and Pittock, 2012). Enhancing the efficiency of water, energy, and land use can ease the trade-offs and resource conflicts. Ensuring resource use efficiency, however, will not be sufficient to sustain food, water, and energy security in the long-run unless natural resources and ecosystems are conserved and used sustainably. The natural resource base and health of the ecosystem set the conditions for sustainable production (Rasul, 2014; FAO, 2014). Finally, ensuring healthy lives cannot be achieved by achieving a particular goal; it depends on multiple goals ranging from ensuring food, water, and energy to inclusive growth, healthy ecosystems, and protection of the environment. Like the food, water, and energy nexus, the SDGs are closely interlinked. Thus food, water, energy security, and the SDGs need to be addressed in an integrated way in South Asia.

Despite the inherent interconnectedness of food, water, and energy, little effort has been made in South Asia to understand the interdependencies in terms of resource use and policies. Understanding and managing the links among food, water, and energy is essential for formulating policies for more resilient and adaptable societies (Newell et al., 2011). This paper seeks to deepen the understanding and to explore policy options for minimizing trade-offs and maximizing synergies among the three sectors, with a view to supporting the formulation of cross-sectoral policies that will result in more resilient and adaptable societies and success in achieving the SDGs. It assesses the trends and issues in food, water, and energy security in South Asia and their interconnected challenges; how policy and institutional factors drive unsustainable use of resources; the environmental, social, and economic implications; and technological options to manage trade-offs and enhance synergies. The final section presents a broad framework for better coordination among the three sectors.

2. Key trends and patterns in food, water and energy security

South Asia is one of the most dynamic regions of the world. High population growth, rapid urbanization, fast economic progress, and industrialization, have increased demand for resources, including food, water, and energy, and intensified their use, with serious implications for the environment and long-term security of these sectors. South Asian agriculture is dominated by small and marginal farmers, the ratio of agricultural land to agricultural population is about 0.38 ha/person, compared to more than 11 ha/person in developed countries. With 6% of the world's land, and 25% of the population, the per capita availability of land is 4–6 times lower than the world average. South Asia is also one of the world's most water scarce regions, with less than 5% of the world's annual renewable water resources. Over 90% of total water withdrawals in the region are used for agriculture. About 39% of cropland is irrigated, and irrigated agriculture accounts for 60–80% of food production (World Bank, 2013). Rice, the major staple, is mostly grown under flooded or submerged conditions. Agriculture consumes about 90% of water use and 20% of energy. Groundwater has become the major source of irrigation in the region providing close to three-fifths of irrigation water (Bhaduri et al., 2011; Mukherji and Shah, 2005). About 60% of the population in India and 65% in Pakistan depend on groundwater for irrigation (Qureshi et al., 2010). Irrigation efficiency is low, water productivity is less than one-fifth of that in the world's large food producing countries (Shah, 2009). South Asia faces a widespread energy crisis. Around 63% of the population lack access to electricity (600 million people) while 65% use biomass for cooking (Rasul, 2014). The main source of energy is imported oil; South Asia's oil imports are expected to double by 2020. Climate change is expected to exacerbate the food, water, and energy challenges. The key trends and issues in food, water, and energy security in South Asia are summarized in Table 1.

3. Factors driving unsustainable practices

What drives the unsustainable use of resources? To understand the opportunities better, it is important to understand the driving forces and context of resource scarcity. The following paragraphs present a short overview of the root causes of the problem.

3.1. Current policy approaches to ensuring food security in South Asia

To ensure food self-sufficiency, all the South Asian countries have adopted policy measures to induce farmers to increase food production, including providing subsidies for agro-chemicals, energy use, and irrigation. Specifically they have focused on increasing the production of the principal food crops of rice and wheat by subsidizing the supply of modern agricultural inputs – seed of high yielding varieties (HYVs), fertilizers, pesticides, irrigation, and machinery. Measures were taken to

Table 2
Cross-sectoral externalities and socioeconomic and environmental impacts of sectoral policies.

Cross-sectoral impacts	Implications for sustainability and the SDGs
Policy: Subsidies for agrochemicals	
Food: Both positive and negative – Higher yields, lower food prices. – Excessive use of agrochemicals. – Intensifies pressure on irrigated crops, increases mono-cropping and reduces diversity of agriculture. – Affects agricultural productivity in the long-run.	**Economic** – Inefficient allocation of resources. – Fiscal burden on government. – Constraints for investment in agriculture infrastructure, research, and development. – Increasing dependence on agrochemicals – Disincentive for use of organic fertilizers and environmentally friendly pest, insect, and disease management. – Stagnation/decline in productivity of the rice-wheat system. – Long-term loss of productivity of land and water and threat to agricultural sustainability [*SDG 2, 2*].
Water: Negative – Eutrophication of surface water and contamination of groundwater. – Overuse of surface and groundwater. – Water pollution and degradation, affects aquatic life. – Pollution of drinking water. – Loss of aquatic diversity.	**Social** – Deteriorating quality of drinking water. – Cost of water purification for public use. – Concern about food safety – pesticide residues in food chain. – Increased waterborne and water-related disease. – Adverse impact on public health and healthy lives [*SDG 3, 6*].
Energy: Negative – Excessive use of agrochemicals. – increased use of energy for production and transportation of agrochemicals. – Subsidized agrochemicals lead to water and energy intensive crops.	**Environmental** – NPK imbalance. – Soil salinity, waterlogging, land degradation. – Eutrophication of freshwater. – N_2O emissions, air pollution. – Arsenic contamination in soil and water. – Loss of biodiversity, degradation of ecosystems that support food production [*SDG 15*].
Policy: Subsidies for energy for irrigation	
Food: Positive and negative – Increased food production, lower food prices. – Reduced food imports, enhanced food and nutrition security. – Change in cropping patterns, switch to energy intensive crops. – Reduced crop and dietary diversity. – Excessive reliance on expensive, imported energy for food production.	**Economic** – Inefficient and excessive use of energy. – Inefficiency in power generation. – High dependency on imported fossil fuel. – Less incentive to adopt energy efficient irrigation technologies. – Sub-optimal use of surface water irrigation – farmers often switch from surface to groundwater irrigation. – Inadequate investment in energy. – Poor and unreliable energy system – threats to food and water security and access to energy [SDG 7, 2, 6, 8].
Water: Negative – Free energy encourages excessive water use. – Over exploitation of groundwater. – Wasteful use of water for irrigation. – Less water for other uses.	**Social** – Undermines access to modern energy, health, and rural livelihoods. – Widespread electricity outages. – Individualization of irrigation system, break-down of community-managed irrigation systems – loss of social capital. – Unsustainable irrigation and energy systems [SDG 2, 7].
Energy: Negative – Increased demand for energy. – Shortage of energy for alternative uses. – Distortion of market for renewable energy. – Inefficient energy systems.	**Environment** – Increased emission of GHGs. – Depletion of groundwater aquifers and reduced stream flow. – Waterlogging, salinization. – Degradation of environment that affects healthy lives [*SDG 3*].
Policy: Free or subsidized water for irrigation	
Food: Positive – Increased production. – Switch to water intensive crops. – Reduce crop diversity. – Increased cost of lifting groundwater.	**Economic** – Encourages cultivation of water-intensive crops. – Overuse and wastage of water. – Disincentive for adopting water saving technologies and practices. – Inadequate public investments in irrigation. – Inefficient and unsustainable irrigation systems. Irrigation system financially unsustainable.
Water: Negative – Over exploitation of water. – High opportunity cost of water for other uses. – Less water and energy for domestic and industrial use. – Inefficient management of irrigation systems.	**Social** – Depletion of water bodies and drying up of streams, wells. – Affects drinking water supplies, water and sanitation. – Affects fisheries and other aquatic life. – Affects water dependent livelihoods.
Energy: Negative – Shortage of water for other uses such as electricity generation, drinking. – Less energy for domestic and industrial use.	**Environment** – Overuse of water and energy. – Groundwater depletion. – Waterlogging and salinization of soils. – Increased methane emissions. – Less water available for ecology and the environment [SDG 15].

utilize surface and groundwater by expanding irrigation facilities and installing tubewells for groundwater extraction. The favorable policy support in the form of input subsidies, market support, and infrastructure development has changed cropping patterns and farming practices. The area under irrigated rice and wheat has increased tremendously in all South Asian countries. Irrigation has been almost entirely mechanized with either diesel or electricity, which has also increased greenhouse gas emissions (GHGs) (Ahmed et al., 2013); more than 30% of GHG emissions and 20% of methane come from agriculture (Gilbert, 2012). While this has led to substantial increases in crop production, the demise of traditional food crops has had a negative impact on nutrition.

The water resources development strategy has centered on expansion of irrigation to promote food grain production. Water for irrigation is provided free of cost, and the cost of water delivery is highly subsidized. Different systems of water charges are practised in different countries and within the same countries. In Bangladesh, annual operation and maintenance costs were charged at USD 6 per hectare against an actual cost of USD 34 per hectare (FAO, 2011). The total annual subsidy on major irrigation projects in South India from 2004 to 2008 (average over four years) was USD 579 million (Palanisami et al., 2011). In Nepal, operation and maintenance costs are charged at USD 4–5 against an actual cost of USD 42 per hectare (FAO, 2012), and in Pakistan, maintenance of large-scale irrigation schemes is charged at USD 5.5 per hectare against annual costs of USD 23 (Qureshi et al., 2010; Planning Commission, 2012). There are also no effective mechanisms in place to deal with defaults on water changes; with most defaults by large farmers (Mr Thapa, Sunsari Morang Irrigation Project, Nepal, personal communication 11 April 2013).

To promote the use of irrigation facilities, energy for irrigation has been highly subsidized. Electricity is provided free of cost or highly subsidized in some states in India such as Punjab, Haryana, and Andhra Pradesh; in Andhra Pradesh farmers are paying only INR 0.04 per kWh compared to an average supply cost of INR 3.40 per kWh (IFPRI, 2007). As a result of the provision of highly subsidized electricity, the area dedicated to cereals in Punjab has increased from 50% to 75%, mostly to produce rice, which consumes much more water (12,373 m^3/ha) than wheat (3661 m^3/ha) (Mukherji et al., 2011). Electricity tariffs for farmers in India amount to less than 10% of the cost of supply (Badiani et al., 2012). In Pakistan, the subsidy is PKR 3.50 per unit of electricity consumed in agriculture (Planning Commission, 2012). In Bangladesh, there is a subsidy of taka 400 per acre for diesel operated irrigation pumps (Asaduzzaman et al., 2009). Cheap energy and increased use of groundwater for irrigation have increased the agricultural share of electricity consumption significantly. For example, in India the share of agriculture in electricity consumption increased from 3.9% in 1960–32.2% in 1998 (IFPRI, 2007).

4. Consequences of the current policy framework

The current policies on food production promote unsustainable use of irrigation, using more water than is being replaced in the system and high levels of energy. The focus of policies is short-term and primarily on food production, without taking into account the impact on other sectors and long-term sustainability. Although existing policies have been able to increase food production, this has come with huge environmental, social, and economic costs (Table 2) and threatens the long-term sustainability of agriculture and food security as well as achieving the SDGs.

4.1. Environmental costs

Intensive agriculture has accelerated the use of water and energy in food production. Estimates for 2004 indicate that 210 km^3 of water is extracted per year in South Asia for irrigation; with an energy requirement of USD 3.78 billion (Shah et al., 2004; Lele et al., 2013). Incentives provided to increase food production have distorted agricultural input markets, and led to inefficient use of energy, over exploitation of water, and indiscriminate use of pesticides and chemical fertilizers. This has raised serious concerns related to land degradation, water pollution, groundwater depletion, salinity, waterlogging, arsenic contamination, biodiversity loss, the environment, and negative impacts on human health (Pingali, 2007).

In much of Pakistan and the Indian Punjab (Haryana and neighboring states), the cheap energy has led to over-exploitation and wastage of groundwater resources resulting in lowering of groundwater tables, degradation and contamination of groundwater, waterlogging, and salinization (Shah et al., 2004; Qureshi et al., 2010; GOP, 2013). Many recent studies have reported an alarming rate of decline in groundwater levels in many parts of South Asia including the Indo Gangetic Plain, the bread basket of South Asia (Giordano, 2009). The groundwater table is going down by 1 m every three years in high potential green revolution areas in India (Mehta, 2001) and about 30% of the tubewells in the Indian Punjab have become submersible (Swaminathan, 2007). If measures are not taken to ensure sustainable groundwater usage in the next 10 years, all the centrifugal pumps will become non-functional and will need to be converted into submersible pumps, which will require a huge financial investment as well as increased energy to extract water (Swaminathan, 2007).

Waterlogging and salinization have affected nearly 20 million ha in India and are the second most important cause of land degradation. The irrigated areas in semi-arid regions that support large rural populations are of particular concern, such as the western Punjab and Indus valley where large areas of waterlogged saline land are spreading through the intensively irrigated plains. Surface irrigation in South Asia is prone to inefficiency and is in need of urgent attention. For example, in Pakistan the canal irrigation network has deteriorated severely over the years. Estimates indicate that water conservation simply through improving the efficiency of the current irrigation system can improve the water supply by 10–15% (IGC, 2010). Significant investment is needed for improving and expanding the existing irrigation networks in almost all countries in South Asia.

4.2. Social costs

The indiscriminate and excessive use of pesticides and nitrogenous fertilizers associated with more intensive agriculture seriously affects shallow groundwater, and the entry of effluents into rivers and canals is affecting the quality of freshwater. Almost all shallow freshwater is polluted with agricultural pollutants and sewage (Ahmad, 2008). Arsenic contamination of groundwater has been reported in 59 districts in Bangladesh where groundwater is being used intensively for irrigation. About 30 million people are exposed to arsenic toxicity (Ahmed et al., 2007). Recent evidence suggests that arsenic is entering the human food chain through crops (Senanayake and Mukherji, 2014). Waterborne diseases have also continued to increase over the years in spite of government efforts to combat them. In India, 44 million people were affected by water-related diseases in 1998 (FAO, 2012). In India, 55–60% of the population depends on groundwater and in Pakistan 60–65%. The free water and subsidized energy has changed copping patterns, replaced traditional crops with rice as well as changed dietary patterns, diet become cereal dominant (Pingali, 2012).

4.3. Economic costs

The subsidy approach to promoting agriculture is becoming financially unsustainable, with increasing loss of revenues through subsidies and resultant inadequate investment in irrigation and power infrastructure and maintenance. In some countries, the amount of power for agriculture is being reduced and the quality of power is deteriorating as the government struggles to cope with increasing demand (Kumar et al., 2011). For example, farmers in Madhya Pradesh, India, receive only 2–4 h electricity a day for irrigation, and in Rajasthan 6–8 h (Jaitly, 2009). The poor quality of the power (limited, low voltage, off-peak, and unreliable) and frequent interruptions, mean that farmers do not have control over irrigation, which also affects food production. As a result, farmers have shifted towards diesel pumping, which brings problems of air pollution and diesel supply. The subsidies have discouraged farmers from considering alternative cropping systems, or growing high value crops using less water and energy which are capable of generating higher returns both to farmers and the national economy. With high subsidies and guaranteed minimum prices for wheat and rice, Punjab farmers are tied into the rice-wheat farming system (George, 1996; Mukherji et al., 2011), which is a major constraint to diversifying the agricultural system in line with changing demand.

4.4. Impact of policies

The cross-sectoral impact of the various policy measures and consequences for sustainability are summarized in Table 2. While the existing agricultural policy framework has helped increase food grain production in the short-term, it has weakened the long-term sustainability of agriculture and food security in South Asia as a result of the unsustainable exploitation of water and energy (Khan et al., 2009; Pingali, 2007). The existing policies and regulatory frameworks were developed without considering the cross-sectoral consequences and are implemented by agencies working in isolation. The disconnect between the food, water and energy sectors has resulted in the cross-sectoral externalities being ignored and a failure to take into account social, economic and environmental costs.

5. Meeting the challenges: options for managing trade-offs and enhancing synergies

5.1. Technological options

Technological innovations that enable more food to be produced with fewer resources will be critical to address the growing challenge of resource constraints. It will be important to minimize trade-offs and maximize the synergies among the food, water, and energy sectors in a sustainable manner. The policy environment will need to encourage the implementation of such options, and discourage the practices that are likely to have negative impacts in the long-term. There are many different innovative options and technologies already available; some are already being practised in different parts of South Asia on a small scale. This section briefly explores some of the technological, policy, and institutional options available that encourage more efficient use of water and reduction of energy in food production

5.2. Improving irrigation efficiency

At present, irrigation efficiency in South Asia is low, estimated at roughly 40% (Hasanain et al., 2012). Often flood irrigation water is pumped to fields and allowed to flow along the ground among the crops, which is inefficient as it results in high evaporation and runoff (Clemmens and Molden, 2007). More efficient irrigation methods and approaches have been developed that can increase production and reduce water demand (Hanjra and Qureshi, 2010; Saleth and Amarasinghe, 2010). The System of Rice Intensification (SRI), with alternate cycles of drying and wetting, is a promising method for increasing rice productivity while reducing water and energy use and GHG emissions, if properly practised (Ackermann, 2012; Gujja and Thiyagarajan, 2009; ICIMOD, 2007; Sinha and Talati, 2007). This method can also be applied to other crops such as wheat, finger millet, and sugarcane (Kassam and Brammer, 2013). SRI could be particularly suitable in northern India and Pakistan where groundwater supplies have been depleted by excessive use of water for irrigation (Shah, 2007; Uphoff et al., 2011). It is estimated that adoption of SRI over 25% of the rice growing area in India would enable 20 billion m^3 (bcm) water and 632.61 million kWh energy to be saved (Gujja and Thiyagarajan 2009). Water saved through improved irrigation could be made available for other uses (Molden, 2007; Qureshi, 2010) and sustain environmental flow (Smakhtin et al., 2006).

Various micro-irrigation systems such as drip and sprinkler methods can also enhance irrigation efficiency in suitable areas. Evidence from field research in different parts of Asia suggests that drip and sprinkler methods can result in water savings of 40–80% and increase crop productivity by 100% if properly applied (Sivanappan, 1994; Palanisami et al., 2011). Narayanamoorthy (2008) suggested that these technologies can raise the efficiency of water use in irrigation to between 60% (sprinkler) and 90% (drip). Furrow irrigation and raised bed planting can also reduce water use (by 35%) and improve yields (by 10%) (Du et al., 2010); zero tillage systems also use less water. Introduction of these technologies, together with careful timing of irrigation (e.g. in the evening rather than the morning) can reduce water use and increase yields of fruit, sunflower, pulses, vegetables, and other high value products, and also help diversify farmer's income (Fang et al., 2010). Drip irrigation for Indian agriculture has the technical potential to cover 37 million hectares by 2030 (McKinsey and Company, 2009), but these technologies are capital intensive. On average it costs about USD 1000 per hectare investment to introduce such technologies (Postel, 2001).

Micro-irrigation on a large scale has the potential to maximize both water productivity and energy efficiency in groundwater irrigation, but not all crops are suited to such techniques. Where micro-irrigation technologies are not appropriate, better irrigation and water management such as scheduling of irrigation, maintenance of irrigation canals, and sowing seeds directly in the field can enhance water use efficiency. Farmers in Malaysia, for example, increased water productivity by 45% through better irrigation management (Brown, 2009). Improving irrigation efficiency and promoting micro-irrigation will require massive private sector involvement which will need to take place in a well-regulated, efficient, and supportive environment with facilitative financing institutions. The costs of irrigation equipment such as motorized pumps have declined substantially in recent decades and several advanced technologies such as drip irrigation are now also available in low-cost versions (Postel et al., 2001). Yet, in the absence of credit, several irrigation technologies remain out of the financial reach of most smallholders and women farmers (Giordano and de Fraiture, 2014). Energy used in irrigation can also be reduced through increased use of technologies like gravity-fed piped water systems, and treadle pumps or other human-powered water lifting devices (Khan et al., 2009). Renewable energy technologies including solar pumped irrigation and production of bioenergy in wasteland can diversify energy sources, provide energy for agriculture, enhance energy security, and reduce the dependency on imported fossil fuel (Biswas and Hossain, 2013; Shah et al., 2014).

5.3. *Policy and institutional responses*

Various policy, institutional, and regulatory measures have been introduced to address the nexus challenges. The Pakistan government is trying to rationalize water fees by charging higher fees for high water demanding crops such as sugarcane (Planning Commission, 2012). In India, some states are trying to regulate and ration electricity in agriculture through random power cuts; others are gradually reducing the electricity subsidy for irrigation. One important measure is the Jyotirgram Yojana (rural lighting scheme) in Gujarat, in which the electricity feeders are segregated between agriculture and other uses and electricity for irrigation is rationed to limit water use (Mukherji et al., 2012; Shah, 2012). This approach has helped to increase the quality of the power supply for normal users, but has not motivated farmers to adopt water and energy saving technologies. Segregation of electricity lines also requires a huge investment in infrastructure, which is beyond the capacity of many states. Other efforts are underway to involve farmers in irrigation water management in order to increase the cost recovery of water fees and achieve better distribution and management of irrigation water (Shah, 2012; Hasanain et al., 2012). Notable efforts have been made in Andhra Pradesh which enacted the Farmers Management Irrigation Act in 1997 to promote participatory irrigation management (Gandhi and Namboodiri, 2009). Success, however, has remained limited due to inadequate support from government irrigation agencies, limited authority, unequal distribution of power, and weak institutional capacity. Except in Andhra Pradesh and West Bengal, participatory irrigation management has remained marginal (Gandhi and Namboodiri, 2009; Lele et al., 2013).

6. Discussion and conclusions

South Asian countries face mounting challenges in meeting the growing demand for food, water, and energy in the face of competing demand for resources and increasing environmental pressure. To increase cereal production, countries have introduced many policy initiatives including providing incentives through subsiding water and energy and guaranteeing prices. While such incentives have helped increase cereal production, they have also increased the demand for water and energy, led to degradation of the resource base, and contributed to an increase in water-related disease. Although the food, water, and energy sectors are inherently interconnected, the connection in terms of policy and implementation is weak. Development of policies and approaches without regard for cross-sectoral consequences, and poor sectoral coordination and institutional fragmentation, have triggered an unsustainable use of resources and threatened the long-term sustainability of food, water, and energy security in the region. Free water and subsidized electricity have not only encouraged overexploitation of resources, they have also led to under-investment in water and energy-saving technologies and approaches and hindered crop diversification and broad-based agricultural growth in line with the comparative advantages. Efforts should be made to integrate environmental considerations in the pricing of water, energy and other natural resources so that prices reflect social costs and the opportunity cost of alternative uses of resources. Special care should be taken, however, to mitigate the immediate effects of changing pricing and fiscal mechanisms on poor and smallholder farmers. Resources saved through changing pricing mechanisms could be spent in the development of irrigation, water, energy, and other rural infrastructure, agricultural research, renewable energy, and water-saving technologies, as well as farmers' education on sustainable agriculture and resource management (Sharma, 2012). Such policies will not only support balanced development of food, water, energy security but also contribute to achieving the SDGs.

Our analysis reveals that opportunities lie in choosing more water and energy efficient and environmentally-friendly technologies in increased food production (Hasanain et al., 2012). It is important to get the price right and phase out environmentally harmful subsidies gradually. Special attention needs to be paid to the impacts of subsidy withdrawal on the poor, and a food safety net needs to be provided. However, technology alone may not be sufficient. More importantly, greater policy coherence among the three sectors will be critical for moving towards a more efficient, equitable, and sustainable use of resources (Nilsson et al., 2012). The decision-making framework urgently needs a paradigm shift that recognizes cross-sectoral externalities, explores feasible trade-offs, and helps policymakers achieve greater policy coherence, integrating environmental considerations in the pricing of water, energy and other natural resources so that prices reflect social costs. The nexus approach is a system-wise approach that recognizes the inherent interdependencies of the food, water, and energy sectors for resource use and seeks to optimize the trade-offs and synergies, and can thus help provide such a framework. It can be used in the design of integrated policies and strategies and provides a means for systematically assessing cross-sectoral interactions, identifying areas of interconnections, and identifying options. By enhancing understanding of the interconnectedness among the food, water, and energy sectors, the nexus approach will also help to strengthen cross-sectoral coordination.

6.1. Towards an enabling policy framework for managing nexus challenges

The nexus approach requires a major shift in the decision making process towards taking a holistic view and developing institutional mechanisms to coordinate the actions of diverse actors and strengthen complementarities and synergies among the three sectors. Fig. 2 suggests a generic framework for integrating policies and strategies in the three sectors and supporting the move from a sectoral to a holistic approach. This should be seen as a broadly explorative proposal showing suggested key elements; development of a detailed framework is beyond the scope of this paper. The key elements of the framework are strengthening cross-sectoral coordination, harmonizing public policies, aligning cross-sectoral strategies and incentive structures, strengthening regulation, and facilitation of nexus smart investment and technologies. Some of the specific approaches are discussed in more detail below.

- **Strengthen cross-sectoral coordination**: appropriate mechanisms need to put in place to strengthen horizontal and vertical integration among the three sectors. Strengthening the role of the national planning commissions or establishing a high level commission with representatives from the three ministries, think tanks, and civil society with a mandate to

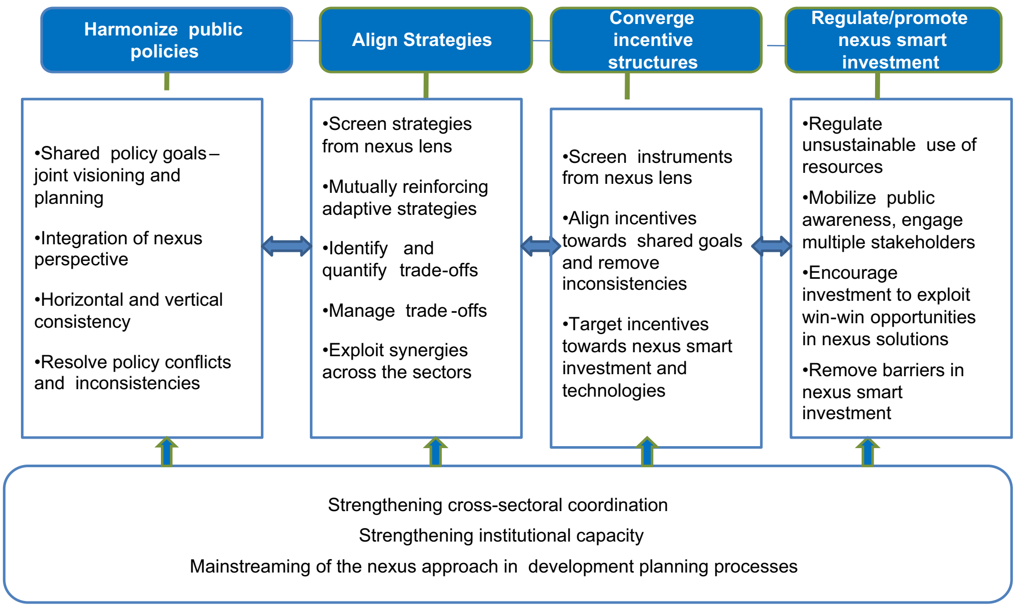

Fig. 2. Policy framework for managing the nexus.

oversee the coordination of the three sectors could be useful. Strengthening institutional capacity for understanding the dynamics and interlinkages among the three sectors at different scales, and introducing the nexus perspective into planning and implementation, are essential for promoting mutually reinforcing polices and achieving multiple goals. Increasing dialogue among the key actors of three sectors is also critical.

- **Harmonize cross-sectoral policies**: policies should be harmonized among the three sectors taking into account the interdependencies of resources in order to minimize cross-sectoral conflicts, maximize synergies, and achieve policy objectives using a systems approach. Policy strategies and instruments employed in achieving sectoral goals need to be harmonized to ensure systematic promotion of mutually reinforcing strategies and instruments and resolve policy conflicts in order to meet the competing demands for resources.
- **Align cross-sectoral strategies:** coordination of strategies across the sectors is essential for exploiting complementarities and synergies and minimizing trade-offs, and achieving optimal alignment of the strategic objectives. It will be necessary to examine strategies in the three sectors from a nexus perspective and identify areas of trade-offs and options for synergies in order to develop and promote mutually reinforcing strategies.
- **Converge cross-sectoral incentive structures:** the incentive structures need to be converged and reoriented towards promoting water and energy saving technologies and encouraging investment in enhancing the efficiency of water and energy, and away from the policy distortion towards water and energy intensive food production. Subsidies for groundwater irrigation need to be progressively reduced, and operating and maintenance costs of canal irrigation fully recovered, to make irrigation systems financially viable and environmentally sustainable. Barriers to the adoption of water harvesting, water efficient technologies, and renewable energy options should be removed.
- **Regulate unsustainable practices and promote technological and institutional innovations.** As food production depends heavily on groundwater, and the link between groundwater and energy is strong, it is important to establish a groundwater management framework to regulate and facilitate the optimal use of groundwater in a rational and sustainable manner based on availability and recharge conditions. While in certain areas groundwater is depleting, in others such as the Nepalese Terai, Orissa, North Bihar, North Bengal, and eastern Uttar Pradesh, there is still scope for further development of groundwater resources (Hassan et al., 2012). Critical areas where groundwater levels are falling fast should be demarcated and regulated to avoid an ecological crisis. It is important to raise public awareness and advocate for the responsible use of groundwater resources. Involving farmers in water and energy management is vital for the sustainable use of resources.
- **Encourage investment in infrastructure development**: investment in energy and water saving technologies and renewable energy options should be encouraged through innovative policies and institutional support to decouple intensity of resource use from food production. Effective strategies should be designed to attract investment to exploit win-win opportunities such as production and use of renewable energy, for example through hydropower, solar-powered water pumps for irrigation, generation of electricity from crop residues, production of biogas from manure, and introduction of trees or perennials on farms to produce wood for on-farm energy purposes.
- **Create an interdisciplinary knowledge base**. It is important to create an interdisciplinary knowledge base, and disseminate knowledge that can offer integrated solutions and a balanced approach for well-informed decision making guided by the nexus approach.

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Annex 1

See Table A1 here.

Table A1
Sustainable Development Goals.Source: UN (2015).

Goal 1	End poverty in all its forms everywhere.
Goal 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
Goal 3	Ensure healthy lives and promote well-being for all at all ages.
Goal 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
Goal 5	Achieve gender equality and empower all women and girls.
Goal 6	Ensure availability and sustainable management of water and sanitation for all.
Goal 7	Ensure access to affordable, reliable, sustainable and modern energy for all.
Goal 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
Goal 9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
Goal 10	Reduce inequality within and among countries.
Goal 11	Make cities and human settlements inclusive, safe, resilient and sustainable.
Goal 12	Ensure sustainable consumption and production patterns.
Goal 13	Take urgent action to combat climate change and its impacts.
Goal 14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
Goal 15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
Goal 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
Goal 17	Strengthen the means of implementation and revitalize the global partnership for sustainable development.

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